Unification of Quantum Coherence, Time, and Gravity through Irreversible Interaction Events

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Abstract

We propose a unified framework in which quantum measurement, the arrow of time, and effective gravitational phenomena emerge from a single ontological primitive: irreversible interaction events. An event is represented operationally by a non-invertible completely positive, trace-preserving (CPTP) map, while unitary evolution and spacetime geometry are treated as effective, emergent descriptions. Time arises as a partial order induced by irreversible state-restricting events, and gravitational time dilation emerges from spatial variations in event density. An Event Equivalence Principle is introduced, according to which gravitational effects manifest universally as a rescaling of event occurrence rates, independent of particle mass. The framework yields falsifiable predictions for gravity-induced decoherence and is shown to be consistent with existing experimental bounds.

1 Introduction

The tension between reversible unitary dynamics and irreversible quantum measurement remains a central issue in quantum foundations. Simultaneously, gravity is described geometrically in general relativity, while quantum theory lacks an intrinsic notion of spacetime.

We argue that both difficulties stem from treating irreversibility as derivative rather than fundamental. In this work, irreversible interaction events are taken as ontological primitives. Unitary evolution and spacetime geometry emerge as effective descriptions of the statistical structure of such events.

2 Irreversible Events

An event is defined as a physical interaction that irreversibly restricts the set of physically accessible states. Operationally, an event is represented by a CPTP map without a completely positive inverse. This representation is not taken as an ontological commitment to unitary dilation in a larger Hilbert space, but as a practical encoding of irreversibility at the level of quantum states.

$$\Phi(\rho) = \sum_k M_k \, \rho \, M_k^\dagger, \qquad \nexists \, \Phi^{-1} \tag{1}$$

Unitary evolution is interpreted as an effective interpolation valid when event density is sufficiently low. Measurement is a subclass of irreversible events characterized by outcome resolution.

2.1 Event Equivalence Principle

We postulate the **Event Equivalence Principle**:

In any local physical process, variations in gravitational potential manifest exclusively as a uniform rescaling of event occurrence rates, independent of the nature of the system, massive or massless.

This principle plays a role analogous to the equivalence principle in general relativity. It implies that gravitational effects are universal and do not rely on particle mass or specific interaction mechanisms.

3 Emergent Time from Event Ordering

Time is defined relationally as a partial order among events. An event E_i precedes E_j if the occurrence of E_i reduces the set of accessible states prior to E_j. No background time parameter is assumed.

Operational duration is identified with the accumulation of events along a physical trajectory. A clock is any system whose behavior is governed by a stable event count.

$$\tau(\gamma) \propto N_E(\gamma) = \int_\gamma \rho_E(\lambda)\, d\lambda \tag{2}$$

Here λ is an arbitrary monotonic order parameter along an event sequence, analogous to an affine parameter in general relativity. Physical meaning is attributed only to the integral, not to the parameter itself.

4 Emergent Gravity and Metric Reconstruction

Spatial variations in event density lead to differential rates of event accumulation. Regions with higher event density exhibit slower operational time, reproducing gravitational time dilation.

In the coarse-grained limit, an effective metric description becomes possible. The metric component g_{00} is reconstructed from event density via the definitional relation:

$$\rho_E(x) \propto \sqrt{-g_{00}(x)} \tag{3}$$

The functional form is motivated by correspondence with the Newtonian limit. In weak fields,

$$g_{00} \approx -(1 + 2\Phi/c^2) \quad \Rightarrow \quad \sqrt{-g_{00}} \approx 1 + \Phi/c^2 \tag{4}$$

This ensures a linear correction in gravitational potential, consistent with classical gravitational time dilation.

5 Gravity-Induced Decoherence and Experimental Constraints

Variations in gravitational potential rescale local event density and can induce decoherence. By the Event Equivalence Principle, this effect is universal and not intrinsically tied to particle mass.

$$V(t) = \exp\left[-\gamma\, \rho_0\, \frac{\Delta\Phi}{c^2}\, t\right] \tag{5}$$

Satellite-based quantum communication experiments with $\Delta\Phi/c^2 \sim 10^{-10}$ and $t \sim 10^{-2}\,\mathrm{s}$ show no visibility loss, constraining

$$\gamma\, \rho_0 \lesssim 10^{12}\,\mathrm{s}^{-1} \tag{6}$$

The theory is therefore explicitly falsifiable.

6 Born Rule and Scope

The Born rule is not fully derived here. We note that irreversible state restriction combined with repeated event statistics naturally selects the squared-norm measure, consistent with envariance-based and decision-theoretic approaches. A complete derivation is left for future work.

7 Conclusion

By elevating irreversible interaction events to fundamental status and introducing the Event Equivalence Principle, we provide a unified and falsifiable framework connecting quantum measurement, time, and gravity. Unitary dynamics and spacetime geometry emerge as effective descriptions of underlying event statistics.

References

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